Chapter 4: Forest Carbon Sequestration and Products Storage

4.1 Net Sequestration of CO_2 in Forest Ecosystems and Forest Products

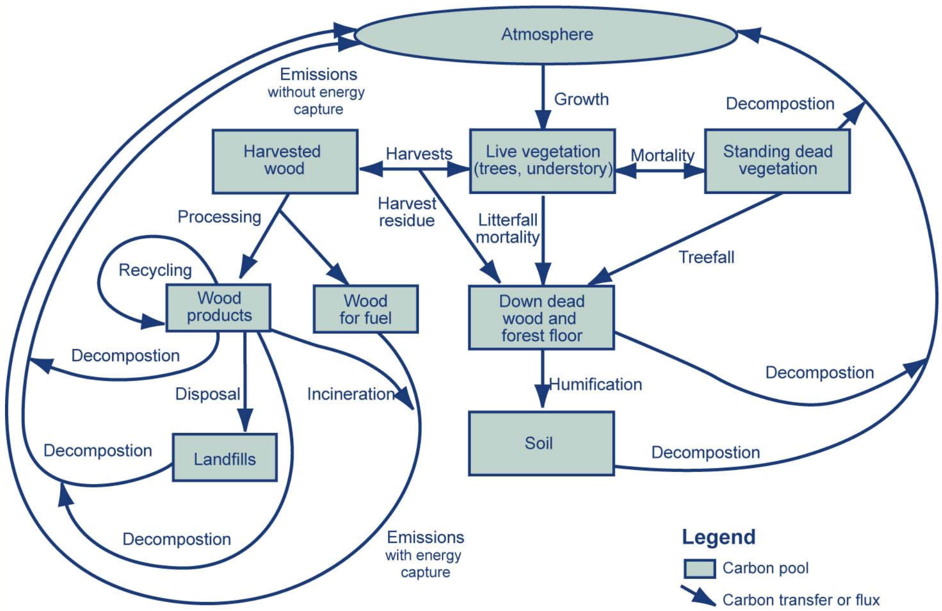
Carbon dioxide is continually exchanged between forest ecosystems and the atmosphere as illustrated by the pools and fluxes in Figure 4-1. Photosynthesis leads to the conversion of carbon dioxide into organic carbon in growing plants, and some of the carbon thus sequestered as plant biomass is subsequently lost through respiration. A large net flux of carbon from atmosphere to tree accompanies early tree growth. Over time, the net rate of exchange decreases due to increasing carbon loss through respiration or the loss and subsequent decomposition of plant material as litter and woody debris. A large amount of carbon is released to the atmosphere as trees die and decompose. Other mechanisms of carbon loss from forest systems include physical removal of organic matter or rapid loss through natural disturbance, such as fire. A significant form of removal in the United States is harvest of wood, but carbon can also be removed through runoff or leaching through soil. Subsequent forest regeneration and growth can then reestablish the section of forest as a sink of atmospheric carbon dioxide. The continuous exchange of carbon with the atmosphere is by far the most significant role of forests in the U.S. greenhouse gas inventory; the net flux of carbon dioxide from the atmosphere to forest ecosystems and harvested wood products in 2001 is estimated at 759 Tg CO_2 eq. Thus, forest carbon budgets are the focus of this chapter.

Forest management is an activity involving the regeneration, tending, protection, harvest, and utilization of forest resources to meet goals defined by the forest landowner. Forest management regimes vary by forest ecosystem, landowner objectives, and economic possibilities. Increasing tree volume per area of forest generally increases carbon sequestration. Relatively passive management may include tree harvest and removal, followed by natural regeneration, or riparian area management that consists of consciously retaining a buffer strip of trees along a watercourse. Intensive management may consist of site preparation, improved stocking, species conversion, planting genetically improved stock, application of pesticides or fertilizer, and improvement cuttings such as thinning or precommercial thinning.

Goals of forest management can focus on one or more outcome, output, or benefit. Example benefits include conservation of soil, water, vegetation, wildlife, carbon, and nutrient resources. Forest management can enhance levels of carbon stocks. Although some practices may decrease carbon storage for a given site-age-type dynamic, generally more carbon may be sequestered in forest systems through improved forest management practices, afforestation, increased productivity, reduced conversion to non-forest uses, lengthened rotations in some systems, and increased proportion and retention of carbon in harvested wood products. Sustainable short-rotation woody crops systems offer the opportunity to rapidly deploy new, faster growing genetic material, sequester carbon in the soil, add to the wood products pool, and provide energy feedstocks as fossil fuel offsets. Afforestation offers significant opportunities to capture and store carbon on lands that are not currently forested. This is a particularly useful tool for marginal agricultural lands.

Improvements in the management of wood products in use and in landfills provide a number of opportunities to reduce emissions and increase sequestration. Continuing development of wood products can increase their durability and recycling potential. This increases opportunities for sequestration in wood products and potentially expands the market for wood products relative to more emission-intensive materials.

Figure 4-1
Summary diagram of forest carbon stocks and carbon transfer among stocks



Source: Adapted from USEPA (2003a), and Heath and others (2003)

Urban trees provide important offset opportunities. Advances in design and deployment of trees in urban environments can provide significant fossil fuel savings for heating and cooling, through microclimate management. Development of urban tree waste management and recycling processes and systems would reduce emissions and increase sequestration opportunities.

This chapter summarizes carbon stocks and stock changes (net carbon fluxes) for U.S. forestland and wood products. Carbon stock estimates are based on extensive forest inventory data, and are consistent with internationally recognized methods for carbon accounting such as the *Revised 1996 IPCC Guidelines* (IPCC/UNEP/OECD/IEA 1997). Summaries of information included in this chapter represent an update of previous national forest carbon budgets (Birdsey 1992, Birdsey and Heath 1995) and were provided to the United States Environmental Protection Agency for the Land-Use Change and Forestry section of the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2001*(EPA 2003a). Estimated carbon budgets are for the year 2001. Principal sources of forest inventory data are compilations of national forest resource statistics for 1987 and 1997 (Waddell and others 1989, Smith and others 2001). Estimates for years after 1997 are projections based on simulation modeling of expected land use change and forest growth, harvest, and utilization.

4.2 Method for Estimating Forest Carbon Mass

4.2.1 Carbon in Forest Ecosystems and Forest Products

Forest structure provides a convenient modeling framework for simulation models to estimate carbon stocks. Carbon stocks in forest ecosystems are modeled as five distinct pools, which are as follows:

- **Trees**: live and standing dead trees including coarse roots, stems, branches, and foliage (live trees only).
- **Understory vegetation:** including the roots, stems, branches, and foliage of seedlings (trees less than 2.5 cm diameter), shrubs, and bushes.
- **Forest floor:** including fine woody debris up to 7.5 cm diameter, tree litter, and humus.
- **Down dead wood:** including logging residue and other coarse dead wood on the ground and larger than 7.5 cm diameter, and stumps and coarse roots of stumps.
- **Soil:** including all organic material in soil excluding any carbon specified for above pools.

Such pools can also be grouped as live vegetation, standing-dead vegetation, the accumulation of dead material on the soil surface, and organic carbon in soil. This is convenient for modeling mechanisms that affect movement of carbon among pools, as illustrated in Figure 4-1. Transfer among pools depends on processes such as growth, mortality, decay, natural disturbances, and the anthropogenic activities of harvesting, thinning, clearing, and replanting. Carbon is continuously cycled through and among these storage pools and between forest ecosystems and the atmosphere.

The net change in forest carbon over an interval of time is not necessarily equal to the net flux between forests and the atmosphere because timber harvests may not result in an immediate release of harvested carbon to the atmosphere. Harvested wood carbon removed from the forest is summarized as two pools, wood products in use, and wood discarded in landfills. As wood products combust or decay over time, the carbon is ultimately reemitted to the atmosphere as carbon dioxide and methane.

The path by which carbon returns to the atmosphere can be important to overall carbon accounting of forest systems. Emissions can occur from wood burned for energy or from burning or decay of wood without energy capture (Figure 4-1). We include these two "pools" of emitted carbon dioxide—with and without energy capture—because they help provide a complete picture of forest carbon budgets. The rate of emission varies considerably among different product pools. For example, if timber is harvested for energy use, combustion results in an immediate release of carbon. Conversely, if timber is harvested and subsequently used as lumber in a house, it may be many decades or even centuries before the lumber decays and carbon is released to the atmosphere. If wood products are disposed of in landfills, the carbon contained in the wood may be released gradually over years or decades as carbon dioxide or methane gas. Wood burned for energy, as a substitute for fossil fuel, is a relatively large pool, and there may be potential for even greater energy recovery from waste wood products.

4.2.2 Background Information in Forest Inventories

The Forest Inventory and Analysis Program (FIA) of the USDA Forest Service has conducted consistent forest surveys based on extensive statistically based sampling of much of the forestland in the United States since 1952. The United States has approximately 300 million hectares of forestland; about 250 million hectares are located in the conterminous 48 States and form the basis for the estimates provided in this chapter (Smith and others 2001). Seventy-nine percent of the 250 million hectares are classified as timberland, meaning they meet minimum levels of productivity and are available for timber harvest. Historically, timberlands in the conterminous 48 States have been more frequently and intensively surveyed than other forestlands. Of the remaining 51 million hectares, 16 million hectares are reserved forestlands (withdrawn by law from management for production of wood products) and 35 million hectares are lower productivity forestlands.

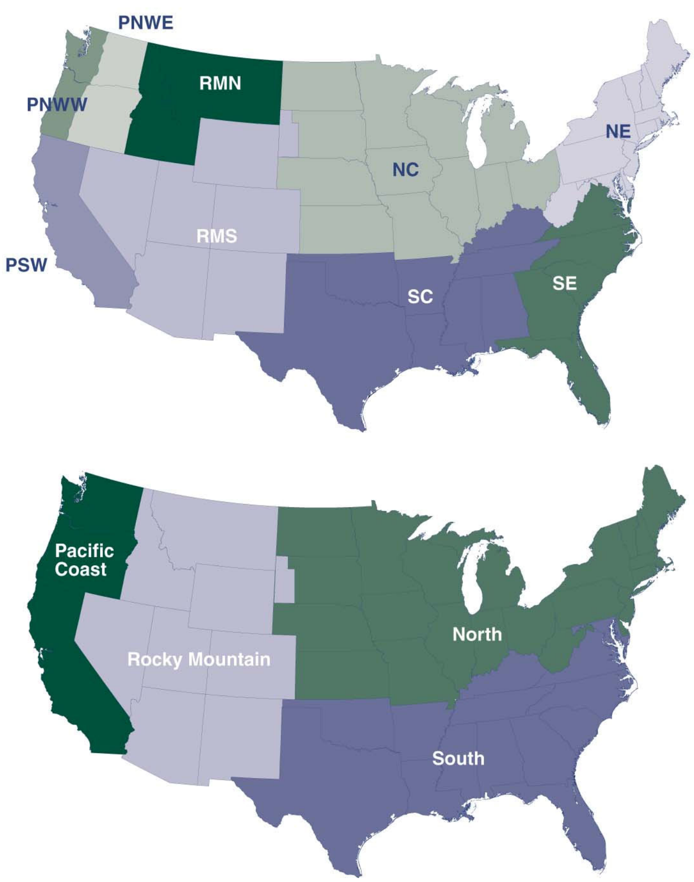
Historically, the main purpose of the FIA program has been to estimate areas, volume of growing stock, and timber products output and utilization factors. Growing stock is simply a classification of timber inventory that includes live trees of commercial species meeting specified standards of quality (Smith and others 2001). Timber products output refers to the production of industrial roundwood products such as logs and other round timber generated from harvesting trees, and the production of bark and other residue at processing mills. Utilization factors relate inventory volume to the volume cut or destroyed when producing roundwood (May 1998). Growth, harvest, land-use change, and other estimates of change are derived from repeated land, aerial, and satellite surveys. Although carbon sequestration is not directly measured in these surveys, the data provide a strong foundation for carbon estimates because the inventories collect data that are highly correlated with carbon stocks. Carbon stocks and fluxes can be estimated using mathematical models and supplemental data from research studies and more intensive monitoring sites.

Forest inventories used in this chapter are based on the State-by-State surveys periodically conducted (every 5-14 years, depending on the State) by regional FIA programs during the 1980s and 1990s. Compilations of these data for 1987 and 1997 are given in Waddell and others (1989) and Smith and others (2001), with trends discussed in the latter citation. FIA has adopted a new annualized design that includes a more extensive and nationally consistent database, which is also conducted State-by-State (Miles and others 2001, <http://www.ncrs.fs.fed.us/4801/fiadb/index.htm>). The annualized survey also includes plans for measurements to facilitate direct estimates of carbon in woody debris, forest floor, and mineral soil from systematically sampled data. However, these data are only beginning to become available from a limited number of States. One feature of the periodic survey data used in this chapter is that some forestlands were surveyed less often than others. Estimates of carbon stock changes can be influenced by the frequency of these surveys.

4.2.3 Estimating Forest Carbon Stocks and Stock Changes

Map 4-1
Regions used for carbon stock summaries

Regions in the upper map are: Pacific Northwest – Westside (PNWW); Pacific Northwest – Eastside (PNWE); Pacific Southwest (PSW); Rocky Mountain – North (RMN); Rocky Mountain – South (RMS); North Central (NC); Northeast (NE); South Central (SC); and Southeast (SE).



The inventory data are converted to carbon using conversion factors or using the model forest carbon budget simulation model FORCARB2 (Birdsey and Heath 1995, Heath and others 2003). The seven component carbon pools, or stocks, are listed in Table 4-1, and relationships among the parts are illustrated in Figure 4-1. Separate estimates are made for each of the forest ecosystem carbon pools: trees, understory vegetation, forest floor, down dead wood, and soils. Stock change, or net annual flux, is based on the difference between two successive estimates of stock divided by the number of years in the interval. Negative fluxes (in parentheses in tables) represent gains in carbon stocks, or removal of carbon dioxide from the atmosphere; this is the convention in all tables and figures. Note that the sign convention is maintained to indicate direction of carbon flux; in the text, direction of flux is indicated by explicitly identifying sources and sinks. Total forest ecosystem stocks or stock changes can be obtained from summing the five constituent pools: similarly, totals for carbon in harvested wood can be obtained from summing the two pools (Table 4-1). Projected carbon stock changes are derived from areas, volumes, growth, land-use changes, and other forest characteristics projected in a system of models (see Haynes and others 2003) representing the U.S. forest sector, including FORCARB2.

Table 4-1 Summaries of forest area, carbon stocks for 1987, 1997, and 2002; and average net annual stock change for the intervals 1987-1996 and 1997-2001

Year/Interval	Stock Jan. 1, 1987	Stock Change 1987-1996	Stock Jan. 1, 1997	Stock change 1997-2001	Stock Jan. 1, 2002
	Tg CO_2 eq.	*Tg CO_2 eq./yr*	*Tg CO_2 eq.*	*Tg CO_2 eq./yr*	*Tg CO_2 eq.*
Forests	174,398		182,092		184,822
Trees	55,579	(469)	60,272	(447)	62,508
Understory	1,642	(9)	1,733	(15)	1,806
Forest floor	15,536	(24)	15,778	29	15,631
Down dead wood	7,541	(54)	8,080	(59)	8,373
Forest soils	94,100	(213)	96,229	(55)	96,504
Harvested Wood	7,035		9,080		10,140
Wood products	4,342	(49)	4,833	(58)	5,123
Landfilled wood	2,693	(155)	4,247	(154)	5,016
Energy Capture		176		185	
Emitted		129		136	
	Tg C	*Tg C/yr*	*Tg C*	*Tg C/yr*	*Tg C*
Forests	47,595		49,695		50,440
Trees	15,168	(128)	16,449	(122)	17,059
Understory	448	(3)	473	(4)	493
Forest floor	4,240	(7)	4,306	8	4,266
Down dead wood	2,058	(15)	2,205	(16)	2,285
Forest soils	25,681	(58)	26,262	(15)	26,337
Harvested Wood	1,920		2,478		2,767
Wood products	1,185	(13)	1,319	(16)	1,398
Landfilled wood	735	(42)	1,159	(42)	1,369
Energy capture		48		51	
Emitted		35		37	

Area of forest	Jan. 1, 1987	Jan. 1, 1997	Jan. 1, 2002
1,000 ha	245,593	250,027	251,029

Parentheses indicate net sequestration.

Table 4-2 Forest carbon stocks, area, and net annual stock change by forest type, 2001

	Stocks			*Area*	*Net Annual Change*	
Forest type	**Biomass**	**Nonliving Plant Mass**	**Soil Organic Carbon**	**Area**	**Biomass**	**Nonliving Plant Mass**
	Tg CO_2 eq.	*Tg CO_2 eq.*	*Tg CO_2 eq.*	*1,000 ha*	*Tg CO_2 eq./yr*	*Tg CO_2 eq./yr*
Eastern Forest Types						
White-red-jack pine	1,252	434	3,423	4,758	(5.7)	1.0
Spruce-fir	1,391	1,163	4,941	6,983	(3.5)	4.1
Longleaf-slash pine	818	396	2,805	5,611	(8.6)	(3.7)
Loblolly-shortleaf pine	3,805	1,742	7,368	21,906	(42.7)	(23.8)
Oak-pine	2,735	1,064	4,156	13,770	(17.1)	(3.3)
Oak-hickory	13,831	3,952	16,877	54,157	(163.4)	(27.4)
Oak-gum-cypress	3,509	1,016	7,087	12,697	(30.5)	(5.6)
Elm-ash-cottonwood	1,232	701	2,482	5,729	(18.1)	(3.8)
Maple-beech-birch	5,998	3,224	11,639	22,748	(43.1)	(1.3)
Aspen-birch	1,307	580	6,370	7,329	(7.6)	(1.5)
Other eastern types	74	20	247	677	26.9	7.5
Nonstocked - East	34	23	219	600	30.4	5.5
Western Forest Types						
Douglas-fir	5,744	3,532	5,269	16,025	49.8	44.1
Ponderosa pine	2,549	1,820	3,291	12,736	58.8	35.9
Western white pine	35	22	37	148	7.5	4.0
Fir-spruce	3,978	2,633	5,532	10,967	32.5	38.1
Hemlock-sitka spruce	1,700	951	2,081	3,613	(0.5)	0.3
Larch	172	106	131	546	(2.6)	(1.0)
Lodgepole pine	1,726	1,039	1,712	7,445	(43.9)	(9.8)
Redwood	215	211	117	373	(1.0)	(0.3)
Hardwoods	2,968	1,763	4,029	13,812	(116.7)	(63.1)
Other western types	1,434	955	1,526	4,618	(112.7)	(40.1)
Pinyon-juniper	2,268	1,808	4,325	20,938	(30.2)	(9.3)
Chaparral	65	57	188	870	16.8	16.8
Nonstocked - West	123	141	652	1,972	(14.3)	(14.8)

Parentheses indicate net sequestration.

Empirical simulation or process models within FORCARB2 estimate ecosystem carbon stocks; estimators are generally classified according to region (Map 4-1), forest type (such as those listed in Table 4-2) and ownership (for example, public versus private forestlands). Live tree carbon and standing dead tree carbon are estimated from stand-level volumes from the inventory data. The volume-to-biomass coefficients are published in Smith and others (2003). Understory carbon is estimated from forest inventory data and equations based on estimates in Birdsey (1996). Forest floor carbon is estimated from the forest inventory data using an empirical simulation model (Smith and Heath 2002). Estimates of carbon in down dead wood are described in Annex O of Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2001 (EPA 2003a). Estimates of soil carbon are based on data from the STATSGO database (USDA 1991). Soil organic carbon estimates are made solely according to forest type and do not reflect effects of past land use. Some example conversion coefficients used in the forest carbon modeling system are found in Annex O (EPA 2003a).

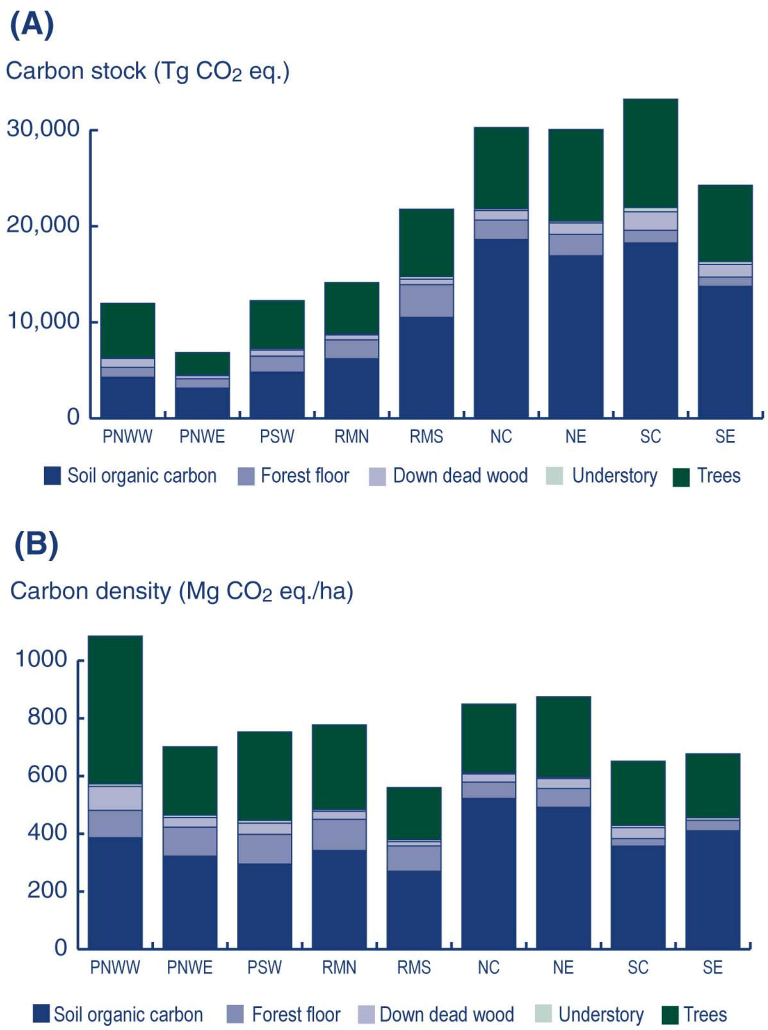
The disposition of harvested wood carbon is simulated according to methods described in Skog and Nicholson (1998). Carbon stocks in wood products in use and wood stored in landfills are based on historical data from the USDA Forest Service (Howard 2001), and historical data as implemented in the framework underlying the NAPAP (Ince 1994) and TAMM/ATLAS (Haynes and others 2003, Mills and Kincaid 1992) models. The carbon conversion factors and decay rates for harvested carbon removed from the forest are taken from Skog and Nicholson (1998). The net carbon stock changes presented in this chapter represent the amounts of carbon that continue to be stored. Annual historical estimates and projections of detailed product production were used to divide consumed roundwood into product, wood mill residue, and pulp mill residue. The rates of carbon decay for products and landfills were estimated and applied to the respective pools. The results were aggregated to produce national estimates. The same disposal rates are used to account for carbon in all wood products produced in the United States, including exported products, whereas carbon in imported wood is not counted.

4.3 Forest Carbon Stocks and Stock Changes, 2001

4.3.1 Estimates by Region, State, Carbon Pool, Forest Type, Age, and Stand Size

Forest areas, carbon stocks, and stock changes for the United States are summarized in Table 4-1. Both carbon dioxide equivalent and carbon summary values are shown for five forest ecosystem pools and two pools of harvested wood products. The rate of increase in ecosystem carbon stocks–net stock change–is somewhat lower since 1997 as compared with the interval from 1987 through 1997. Part of the difference between periods may be due to the timing of forest inventories, or may in part be due to the use of projections after 1997. Organic carbon in soils is the largest carbon pool, followed by carbon in live and standing dead trees. Pools of carbon in harvested wood products are estimated as very similar in size for products in use versus products in landfills. However, the net flux of carbon to landfills is greater. The

Figure 4-2
Forest ecosystem carbon stocks and average stock density according to region and carbon pool, 2001

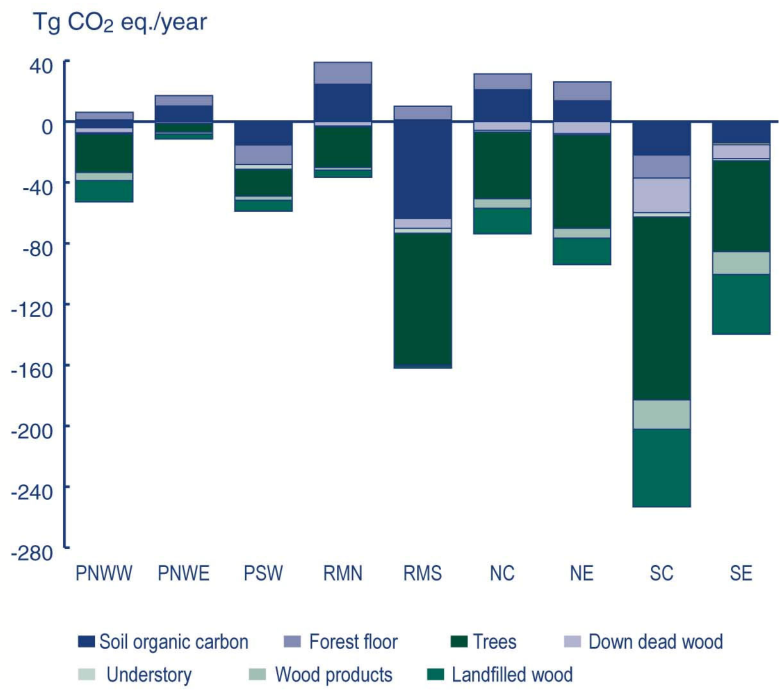


majority of carbon emitted to the atmosphere from harvested wood products is associated with some energy capture from burning.

Total forest ecosystem carbon stocks are greater in the East than in the West (Figure 4-2A). However, regional average values for carbon density, or mass of carbon per unit area (for example, Mg CO_2 eq./ha), do not show such a distinct East-West trend (Figure 4-2B). Thus, the larger pools in the East are principally due to greater forest area (Table 4-2). The most apparent regional trends in ecosystem pool carbon density are: greater carbon in trees in the Pacific Northwest-Westside; greater soil organic carbon pools in northern regions; and smaller pools of down dead wood and forest floor in the South. Net annual stock changes are shown in Figure 4-3, which includes estimated changes in harvested wood product pools. Regional estimates of flux of carbon reemitted to the atmosphere are also included in Figure 4-3. However, the two separate emission fluxes should not be included when summing total flux for a region because those quantities are already included in the net fluxes for wood products and landfills. The greatest net annual increases in carbon stocks were in the South. Area change strongly affects estimates of change in total stocks: regions with a net decrease in forest area since 1997 are the Pacific Northwest-Eastside, Rocky Mountain-North, North Central, Northeast, and Southeast.

Carbon stocks, forest areas, and stock changes for 2001 are shown in Table 4-2 according to forest type. Pool classifications in this table are carbon in biomass, non-living plant mass, and soil. Biomass is live trees plus live understory vegetation. Non-living plant mass includes standing dead trees, down dead wood, and the forest floor. Carbon estimates include aboveground and belowground components. Changes in carbon stock totals as shown in Table 4-2 depend partly on changes in carbon density and partly on changes in total forest area of each forest type. All forest types with a net loss of carbon in biomass during 2001 were accompanied by a net decrease in forest area. Douglas fir, ponderosa pine, and fir-spruce forest types in the West each lost an estimated average of 1 percent of forest area per year since 1997. Other forest types with loss in total carbon stock represent relatively smaller areas of forest, and a portion of area change may be due to reclassification. White-red-jack pine and spruce-fir forests in the East also lost area, but this was estimated at about 1 percent since 1997. For detailed inventory data corresponding to this summary of carbon stocks, see Smith and others (2001).

Figure 4-3
Net annual forest carbon stock change, summarized according to region and carbon pool, 1997-2001



Note: Negative values correspond to sequestration.

Distribution of carbon stocks among forest age classes is shown in Appendix Table C-2 for privately owned and Appendix Table C-3 for publicly owned forests. The tables illustrate that the greater proportion of forest, and thus carbon stocks, in the East are under private ownership while the greater proportion in the West is under public ownership. Distributions according to age are shifted toward older forests on public lands; this is the case for all four regions but is more apparent in the West. Similarly, distribution according to stand size class (Appendix Table C-4) shows a greater proportion in larger size-class stands in the West. Forest land ownership varies by forest type and region. These patterns are illustrated with forest carbon pools (excluding soils) in Appendix Table C-5. Ownership is classified as public or private for timberlands (forests of minimum productivity and available for harvesting). The remaining forestland, both public and private, is either reserved from harvesting or is considered less productive (and thus not managed for wood products). Western forests include a greater proportion of public and reserve/other forest carbon. Similarly, the greater changes (Appendix Table C-6) are in public and reserve/other forest carbon. For more information about forest inventory variables such as forest classifications of ownership, productivity, forest type, and stand size class see Smith and others (2001), and Miles and others (2001).

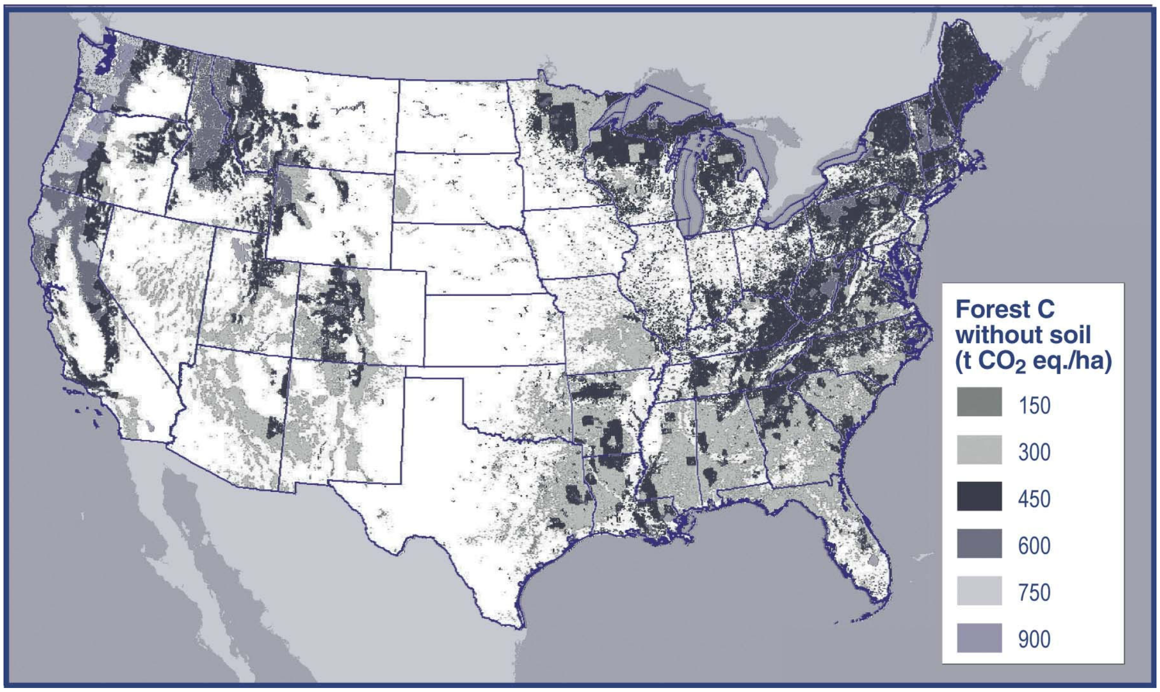
All States in the conterminous United States have forestland. State-by-State totals of forest area, ecosystem carbon stock, stock change, and stock change of harvested wood products for 2001 are shown in Appendix Table C-1. Total stock change per State is the sum of the separate forest ecosystem and products estimates. Estimates of stock change, or flux, for individual States are modeled; a number of States did not have two complete forest inventories as inputs, which can affect the estimates developed by the models. State values for carbon fluxes in wood products, shown in Appendix Table C-1, are based on the amount of wood products produced in the State. Map 4-2 illustrates both the spatial distribution of forest ecosystem carbon and average non-soil carbon density. This map does not include the soil organic carbon and wood products pools, and is therefore not influenced by the relatively large size of this pool. The spatial distributions of net flux of carbon in harvested wood products is influenced by forest management and will not necessarily show the same pattern (these estimates are not yet available in such detail).

4.3.2 Management Activities and Land Use Change

Forest area in the conterminous United States declined by approximately 2.3 million hectares between 1977 and 1987, but area increased by about 4.4 million hectares between 1987 and 1997. Forest area has continued to increase since 1997. These changes in forest area represent average annual fluctuations of less than 0.2 percent. Given the low rate of change in U.S. forestland area, the major influences on the current net carbon flux from forestland are management activities, management intensity, and the ongoing impacts of previous disturbances and past land-use changes. For example, intensified management can increase both the rate of growth and the eventual biomass density of some forest systems, thereby increasing the uptake of carbon. A comparison of carbon density of Southeastern pine stands (10 to 25 years old) found 24 percent greater carbon density in live trees in planted pine stands compared to naturally regenerated stands (156 versus 126 Mg CO_2 eq./ha). Harvesting removes much of the aboveground carbon on forests, but trees may regrow on harvested areas and further sequester carbon. Net ecosystem sequestration associated with harvests depends on factors such as site productivity and decomposition rates. The reversion of cropland to forestland through natural regeneration will cause increased carbon storage in biomass and soils. The net effects of past forest management and land-use change involving forests are captured in the carbon estimates provided in this chapter.

Improved forest management practices, the regeneration of previously cleared forest areas, and timber harvesting and use have resulted in an annual net uptake of carbon during the period

Map 4-2
Average non-soil forest carbon stock density ($t\ CO_2$ eq./ha) over all forestland



from 1987 through 2001 (Table 4-1). Due to improvements in U.S. agricultural productivity, the rate of forest clearing for crop cultivation and pasture slowed in the late 19th century, and by 1920 this practice had all but ceased. As farming expanded in the Midwest and West, large areas of previously cultivated land in the East were taken out of crop production, primarily between 1920 and 1950, and were allowed to revert to forests or were actively reforested. The impacts of these land-use changes are still affecting carbon fluxes for forests in the East. In addition to land-use changes in the early part of this century, carbon fluxes from Eastern forests have been affected by a trend toward managed growth on private land. Collectively, these changes have produced a near doubling of the carbon density in Eastern forests since the early 1950s. More recently, the 1970s and 1980s saw a resurgence of federally supported forest management programs (for example, the Forestry Incentive Program) and soil conservation programs (for example, the Conservation Reserve Program), which have focused on tree planting, improving timber management activities, combating soil erosion, and converting marginal cropland to forests. In addition to forest regeneration and management, forest harvests have also affected net carbon fluxes. Because most of the timber that is harvested from U.S. forests is used in wood products and much of the discarded wood products are disposed of in landfills, rather than by incineration, significant quantities of this harvested carbon are transferred to long-term storage pools rather than being released to the atmosphere. The size of these long-term carbon storage pools has increased over the last century.

A large proportion of non-forest trees in the United States are in urban areas. These urban trees constitute approximately 3 percent of total tree cover in the conterminous United States (EPA 2003a). Methods have been developed for estimating carbon sequestration rates for urban trees of the United States (Nowak and Crane 2002). Net flux of carbon into urban trees for 2001 was estimated at 58.7 Tg CO_2 eq. per year (from Table 6-6 in EPA 2003a). This represents significant carbon accumulation (Table 4-1). Urban trees provide additional favorable GHG benefits beyond accumulating carbon stocks; these include direct effects on energy savings [see Dwyer and others (2000) and Akbari (2002) for further discussion].

4.4 Uncertainty of the Estimates

Carbon stocks and stock changes as provided here are the current estimates of the most likely values, and include some level of uncertainty. Better information such as samples, processes, or models could reduce uncertainty of future estimates. However, we believe the estimates are unbiased, so reductions in uncertainty are not expected to change mean values significantly.

Forest inventories, which are the input data to FORCARB2, include sampling, measurement and modeling errors that contribute to uncertainty. Forest Inventory and Analysis surveys are based on a statistical sample designed to represent the wide variety of growth conditions present over large territories. Although the potential for uncertainty is large, the sample design for forest surveys contributes to limiting the error, and relative error is inversely proportional to degree of aggregation of inventory data (Phillips and others 2000). Similarly, the inventory design contributes to limiting uncertainty about net annual carbon stock change. Estimates from sampling at different times on permanent plots are correlated, and this correlation reduces the uncertainty in stock change variables (Smith and Heath 2001).

Additional sources of uncertainty come from the empirical models used by FORCARB2 to estimate carbon storage in specific ecosystem components, such as forest floor, understory vegetation, and mineral soil. Certainty about model predictions is limited by precision in process definitions, coefficients, and relationships among system components. Uncertainty also arises from extrapolation of the results of site-specific ecosystem studies to very large areas of forestland because such studies may not adequately represent regional or national averages. An important source of uncertainty is attributed to the lack of knowledge about the impacts of forest management activities, including harvest, on soil carbon. Soil carbon impact estimates need to be very precise because even small changes in soil carbon may sum to large differences over large areas; thus, limited understanding of soils can significantly affect overall forest carbon budget estimates (Heath and others 2003).

4.5 Summary of Current Net CO_2 Sequestration for U.S. Forests and Forest Products

Forest ecosystems and forest products represent a significant carbon dioxide sink in the United States. Over 90 percent of the sequestration in agriculture and forests occurs in the forest sector, with an additional 7 percent sequestered in urban trees. Total carbon stocks in forest ecosystems of the conterminous United States are estimated at 184,800 Tg CO_2 eq. (Table 4-1). The net amount of carbon stored in forest ecosystems in the conterminous U.S. increased by an estimated 547 Tg CO_2 eq. This estimate does not include increases in biomass harvested from a portion of U.S. forests, used largely as timber and fuelwood. In the same year, the net increase in carbon sequestered in harvested wood products, which includes long-term storage in landfills, is estimated at 212 Tg CO_2 eq. This net value is the sum of an annual sink in harvested wood of 533 Tg CO_2 eq. and emission of carbon to the atmosphere of 321 Tg CO_2 eq. Fifty eight percent of these emissions included some form of energy recapture associated with the combustion of wood products. Total net sequestration, or gain in carbon storage, by forest ecosystems and harvested wood products for 2001 was 759 Tg CO_2 eq.